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Search for Charged Higgs Bosons in e^+e^- Collisions at Centre-of-Mass Energies between 192 and 202 GeV

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Abstract

A search for pair–produced charged Higgs bosons is performed with the L3 detector at LEP using data collected at centre–of–mass energies between 192 and 202 GeV, corresponding to an integrated luminosity of 233.2 pb^{-1}. Higgs decays into a charm and a strange quark or into a tau lepton and its associated neutrino are considered. The observed events are consistent with the expectations from Standard Model background processes. A lower limit of 67.4 GeV on the charged Higgs mass is derived at 95% confidence level, independent of the decay branching ratio $Br(H^{\pm} \rightarrow \tau\nu)$.

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Introduction

In the Standard Model [1], the Higgs mechanism [2] requires one doublet of complex scalar fields which leads to the prediction of a single neutral scalar Higgs boson. Extensions to the minimal Standard Model contain more than one Higgs doublet [3]. In particular, models with two complex Higgs doublets predict two charged Higgs bosons ($H^{\pm}$). The discovery of a charged Higgs particle would be evidence for physics beyond the Standard Model.

The search is performed in the three decay channels $H^+H^- \rightarrow \tau^+\nu_\tau\tau^-\bar{\nu}_\tau$, $H^+H^- \rightarrow c\bar{s}\tau^-\bar{\nu}_\tau$ [1)] and $H^+H^- \rightarrow c\bar{s}\bar{c}s$. This allows the interpretation of the results to be independent of the branching ratio $Br(H^{\pm} \rightarrow \tau\nu)$.

The results in this letter include the previous lower limit on the mass of charged Higgs bosons established by L3 [4, 5]. Results from other LEP experiments are published in Reference [6].

Data Analysis

This paper describes the search for pair–produced charged Higgs bosons using the data collected in 1999 with the L3 detector [7] at LEP, corresponding to an integrated luminosity of 233.2 pb^{-1}; where 29.7 pb^{-1} were collected at a centre-of-mass energy of 191.6 GeV, 83.7 pb^{-1} at 195.5 GeV, 82.8 pb^{-1} at 199.5 GeV and 37.0 pb^{-1} at 201.8 GeV. The analyses remain almost unchanged since our previous publications at centre–of–mass energies between 130 and 189 GeV [4], with the exception of the four-jet channel which is described in more detail.

The charged Higgs cross section is calculated using the HZHA Monte Carlo program [8]. For the efficiency estimates, samples of $e^+e^- \rightarrow (Z/\gamma) \rightarrow H^+H^-$ events are generated with the PYTHIA Monte Carlo program [9] for Higgs masses between 50 and 95 GeV in mass steps of 5 GeV. About 1000 events for each final state are generated at each Higgs mass. For the background studies the following Monte Carlo generators are used: PYTHIA for $e^+e^- \rightarrow q\bar{q}(\gamma)$, $e^+e^- \rightarrow ZZ$ and $e^+e^- \rightarrow Ze^+e^-$, KORALW [10] for $e^+e^- \rightarrow W^+W^-$, PHOJET [11] for $e^+e^- \rightarrow e^+e^-q\bar{q}$, DIAG36 [12] for $e^+e^- \rightarrow e^+e^-\ell^+\ell^-$ ($\ell = e, \mu, \tau$), KORALZ [13] for $e^+e^- \rightarrow \mu^+\mu^-$ and $e^+e^- \rightarrow \tau^+\tau^-$ and BHAGENE3 [14] for $e^+e^- \rightarrow e^+e^-$. The L3 detector response is simulated using the GEANT program [15] which takes into account the effects of energy loss, multiple scattering and showering in the detector.

Search in the $H^+H^- \rightarrow \tau^+\nu_\tau\tau^-\bar{\nu}_\tau$ Channel

The signature for the leptonic decay channel is a pair of tau leptons with large missing energy and momentum, giving rise to low multiplicity events with low visible energy and uniform acollinearity, the maximum angle between any pair of tracks. The distribution of the visible energy is shown in Figure 1. The performance of the analysis is not affected by the increased centre–of–mass energy, and the event selection remains unchanged since our last publications [4].

The efficiency of the $H^+H^- \rightarrow \tau^+\nu_\tau\tau^-\bar{\nu}_\tau$ selection for several Higgs masses is shown in Table 1. The number of data events and the background expectations are shown in Table 2 for the different centre–of–mass energies. The total number of events selected in data is 47, where 44 background events are expected from Standard Model processes. Almost all of the remaining background comes from W pair production.

[1)] The charge conjugate reaction is included throughout the letter.

Channel	Efficiency (%) for $m_{H^\pm}$ =				
	60 GeV	65 GeV	70 GeV	75 GeV	80 GeV
$\tau^+\nu_\tau\tau^-\bar{\nu}_\tau$	28	30	31	32	33
$c\bar{s}\tau^-\bar{\nu}_\tau$	42	42	43	41	37
$c\bar{s}\bar{c}s$	51	56	60	61	63

Table 1: The charged Higgs efficiencies for various Higgs masses, averaged over centre–of–mass energies and weighted with the luminosity. The efficiency is almost independent of the centre–of–mass energy. The total uncertainty on the efficiency is estimated to be 5%.

Channel	Centre–of-mass energy (GeV)				Total	
	192	196	200	202		
$\tau^+\nu_\tau\tau^-\bar{\nu}_\tau$	6	23	12	6	47	DATA
	5.4	15.4	16.3	6.9	44	Background
$c\bar{s}\tau^-\bar{\nu}_\tau$	21	88	66	34	209	DATA
	22.8	67.2	64	30.4	184.4	Background
$c\bar{s}\bar{c}s$	133	379	384	146	1042	DATA
	139.1	384.9	364.6	162.5	1051.1	Background

Table 2: The number of data events and the background expectations per centre–of–mass energy. The total uncertainty on the background expectations is estimated to be 10%.

Search in the $H^+H^- \to c\bar{s}\tau^-\bar{\nu}_\tau$ Channel

The semileptonic final state $H^+H^- \to c\bar{s}\tau^-\bar{\nu}_\tau$ is characterised by two hadronic jets, a tau lepton and missing momentum. The selection criteria are the same with respect to the analysis at a centre–of–mass energy of 189 GeV [4].

The selection efficiencies are shown in Table 1. The total number of events selected in data is 209, where 184.4 background events are expected from Standard Model processes (Table 2). The background is dominated by the process $W^+W^- \to q\bar{q}'\tau\nu$. Figure 2 shows the average of the masses of the jet–jet and the τ–ν systems, calculated after a kinematic fit imposing energy and momentum conservation for an assumed production of a pair of equal mass particles.

Search in the $H^+H^- \to c\bar{s}\bar{c}s$ Channel

Events from the $H^+H^- \to c\bar{s}\bar{c}s$ channel have a high multiplicity and are balanced in transverse and longitudinal momenta. A large fraction of the centre–of–mass energy is deposited in the detector, typically by four hadronic jets. The selection criteria are slightly modified with respect to the analysis at lower centre–of–mass energies [4], in order to gain sensitivity at higher masses.

Events with an identified electron, muon or photon with energy in excess of 65 GeV are discarded. A neural network [16] is applied to distinguish events with four genuine quark jets from those with two quark jets and two jets from gluon radiation. Further reduction of the QCD background is achieved by requiring the Durham jet resolution parameter, Y^D_{34}, to be greater than 0.003 and by requiring the minimum jet energy to exceed 6% of $\sqrt{s}$.

The charged Higgs production angle distribution is predicted to have a $\sin^2\theta$ dependence, where θ is the polar angle with respect to the beam direction. A cut of $|\cos\theta| < 0.8$ is applied to preferentially reject W pair background.

The analysis of the data taken at $\sqrt{s} = 183$ and 189 GeV has been redone using the criteria described above, superseding the previous analysis [4].

The selection efficiencies are shown in Table 1. The total number of events selected in data is 1042, where 1051.1 background events are expected from Standard Model processes (Table 2). The main contribution to the background comes from W pair decays into four jets. Figure 3 shows the average dijet mass after a kinematic fit imposing four–momentum conservation and equal dijet masses. The low mass tail from the W^+W^- background is due to incorrectly assigned jet pairs.

Results

The number of selected events in each decay channel is consistent with the number of events expected from Standard Model processes, and no significant deviations in the mass spectra are present. No indication of pair–produced charged Higgs bosons is observed. Mass limits as a function of the branching fraction $\mathrm{Br}(H^\pm \to \tau\nu)$ are derived at the 95% confidence level (CL), using the same technique described in Reference [17]. For the $H^+H^- \to c\bar{s}\bar{c}s$ and the $H^+H^- \to c\bar{s}\tau^-\bar{\nu}_\tau$ channels the reconstructed mass distributions (Figures 2 and 3) are used in the limit calculation, whereas for the $H^+H^- \to \tau^+\nu_\tau\tau^-\bar{\nu}_\tau$ channel the total number of data, expected background and expected signal events are used.

The systematic uncertainties on the background and signal are estimated to be 10% and 5% [18] respectively, and come mainly from normalisation errors due to selection efficiencies and cross sections. These errors are included in the confidence level calculation.

Figure 4 shows the excluded mass regions of charged Higgs bosons at 95% CL for the combination of the analyses of each final state as function of the branching fraction $\mathrm{Br}(H^\pm \to \tau\nu)$, including the data at $\sqrt{s}$ between 191.6 and 201.8 GeV as well as those from lower centre–of–mass energies. Table 3 shows the observed and the median expected limits for different values of the branching fraction $\mathrm{Br}(H^\pm \to \tau\nu)$. The region around $m_{H^\pm} = 68$ GeV at low values of $\mathrm{Br}(H^\pm \to \tau\nu)$ can only be excluded at 88% CL, due to the slight excess in data in this mass region (Figures 2 and 3). The statistical significance of this excess is 2.93 σ. Figure 5 shows the observed background confidence level (CL_b) at $\mathrm{Br}(H^\pm \to \tau\nu) = 0.1$ as function of the Higgs mass. The reconstructed mass spectrum for events both in the $H^+H^- \to c\bar{s}\bar{c}s$ and $H^+H^- \to c\bar{s}\tau^-\bar{\nu}_\tau$ channels combined is shown in Figure 6. The events from these two channels are weighted with the respective cross sections corresponding to a value of $\mathrm{Br}(H^\pm \to \tau\nu) = 0.1$. The expected distribution for a 68 GeV Higgs at $\mathrm{Br}(H^\pm \to \tau\nu) = 0.1$ is also shown.

The expected limit reveals a significant improvement on the sensitivity of the data as compared to that from lower centre–of–mass energies. A lower limit on the mass of the charged Higgs boson of

$$m_{H^\pm} > 67.4 \text{ GeV}$$

independent of the branching fraction is obtained.

$\mathrm{Br}(\mathrm{H}^{\pm} \to \tau\nu)$	Limits at 95% CL	
	observed	median expected
0.0	76.5	75.9
0.5	70.5	73.8
1.0	79.9	79.2
any (0.1)	67.4	74.9

Table 3: Observed and median expected limits at 95% CL for different values of the branching fraction $\mathrm{Br}(\mathrm{H}^{\pm} \to \tau\nu)$. The minimum observed limit, independent of the branching fraction, is at $\mathrm{Br}(\mathrm{H}^{\pm} \to \tau\nu) = 0.1$.

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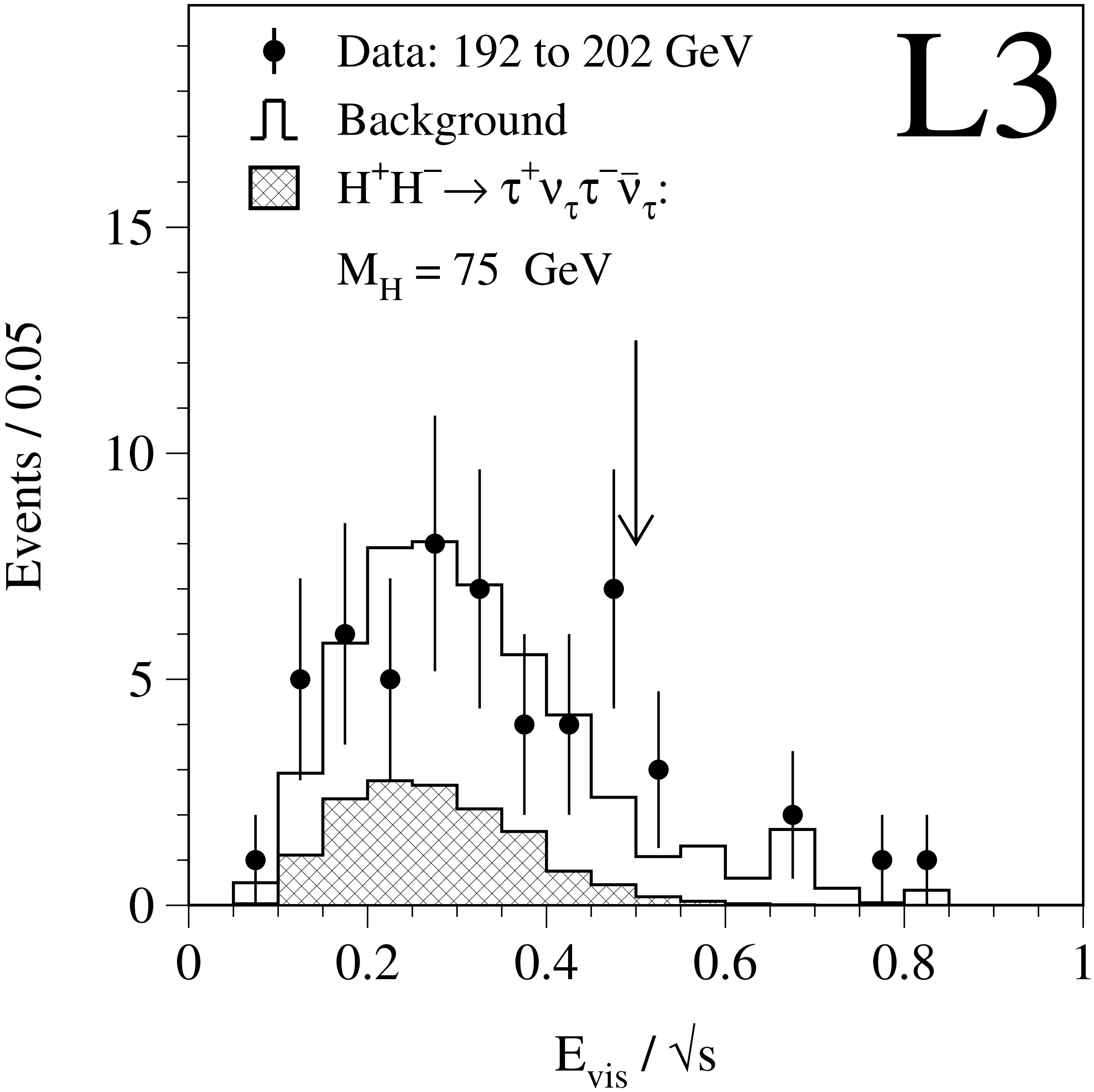

Figure 1: Distribution of the visible energy of the event normalised to the centre–of–mass energy, for the $H^+H^- \to \tau^+\nu_\tau\tau^-\bar{\nu}_\tau$ channel after all other cuts have been applied. The arrow shows the position of the cut. The hatched histogram indicates the expected distribution for a 75 GeV Higgs at $\mathrm{Br}(H^\pm \to \tau\nu) = 1$.

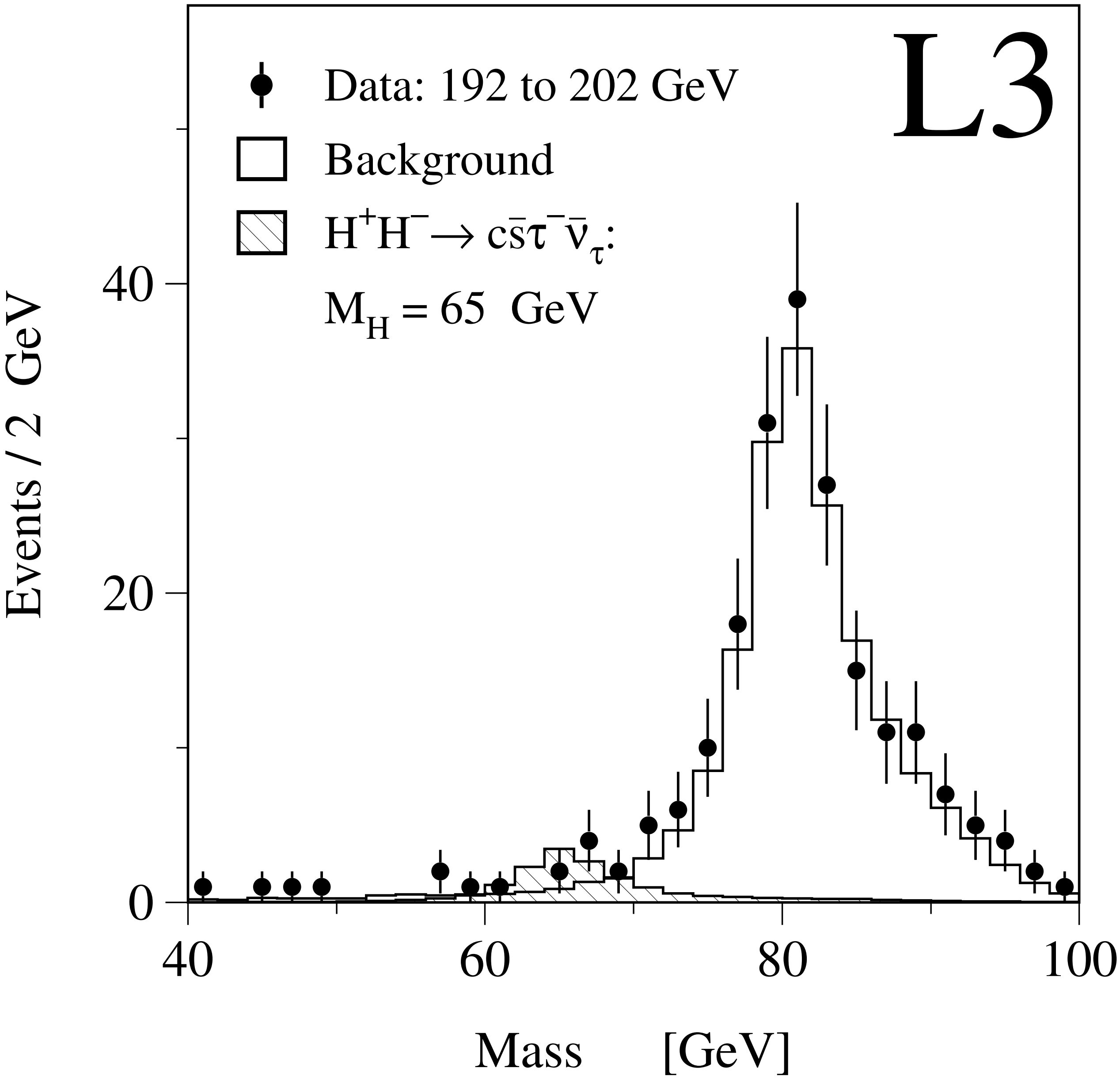

Figure 2: Reconstructed mass spectrum for data and background events in the $H^+H^- \to c\bar{s}\tau^-\bar{\nu}_\tau$ channel. The expected distribution for a 65 GeV Higgs at $Br(H^\pm \to \tau\nu) = 0.5$ is superimposed.

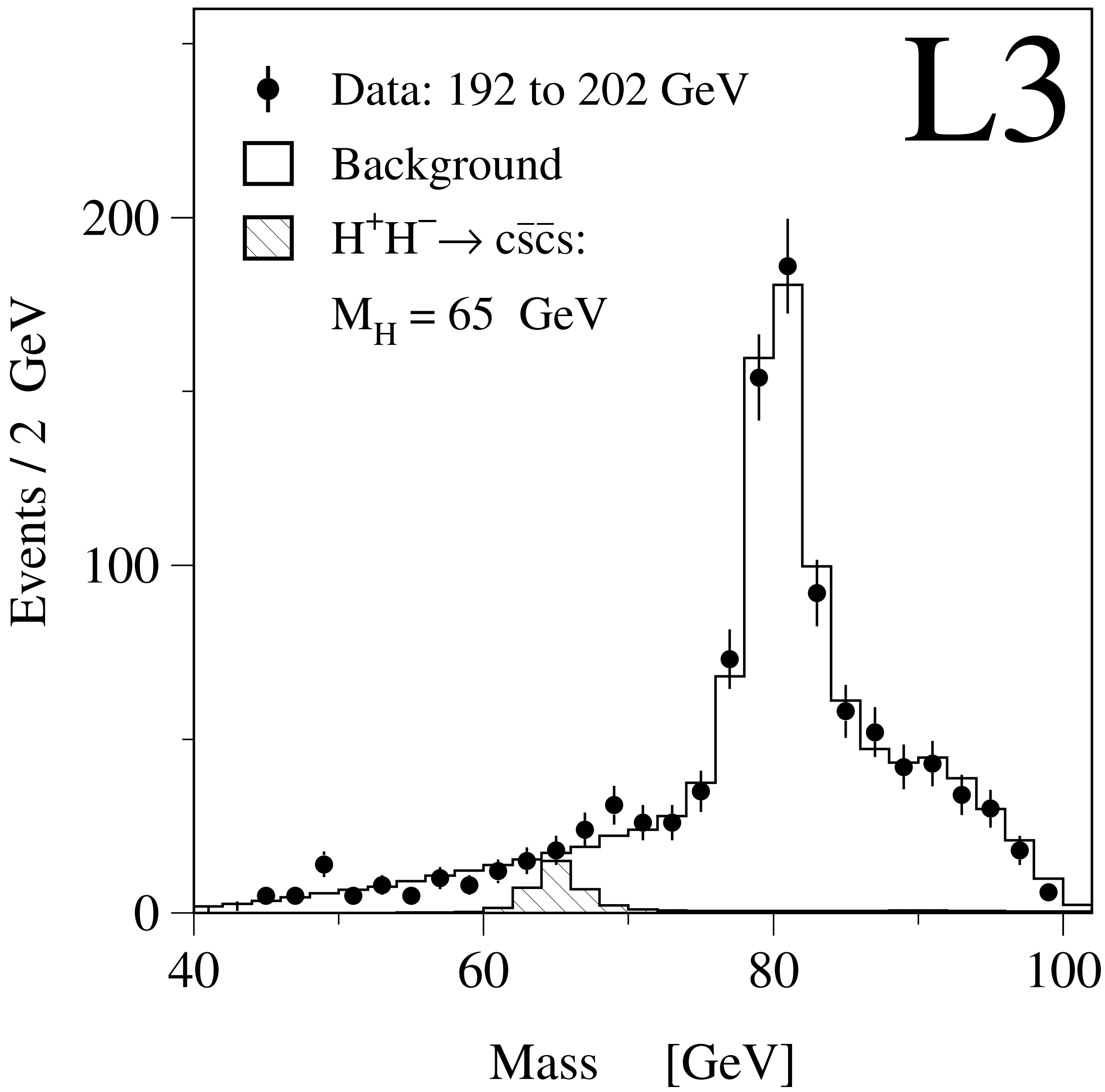

Figure 3: Distribution of the mass resulting from a kinematic fit, with assumed production of a pair of equal mass particles, for data and background events in the $H^+H^- \rightarrow c\bar{s}\bar{c}s$ channel. The hatched histogram indicates the expected distribution for a 65 GeV Higgs at $Br(H^{\pm} \rightarrow \tau\nu) = 0$.

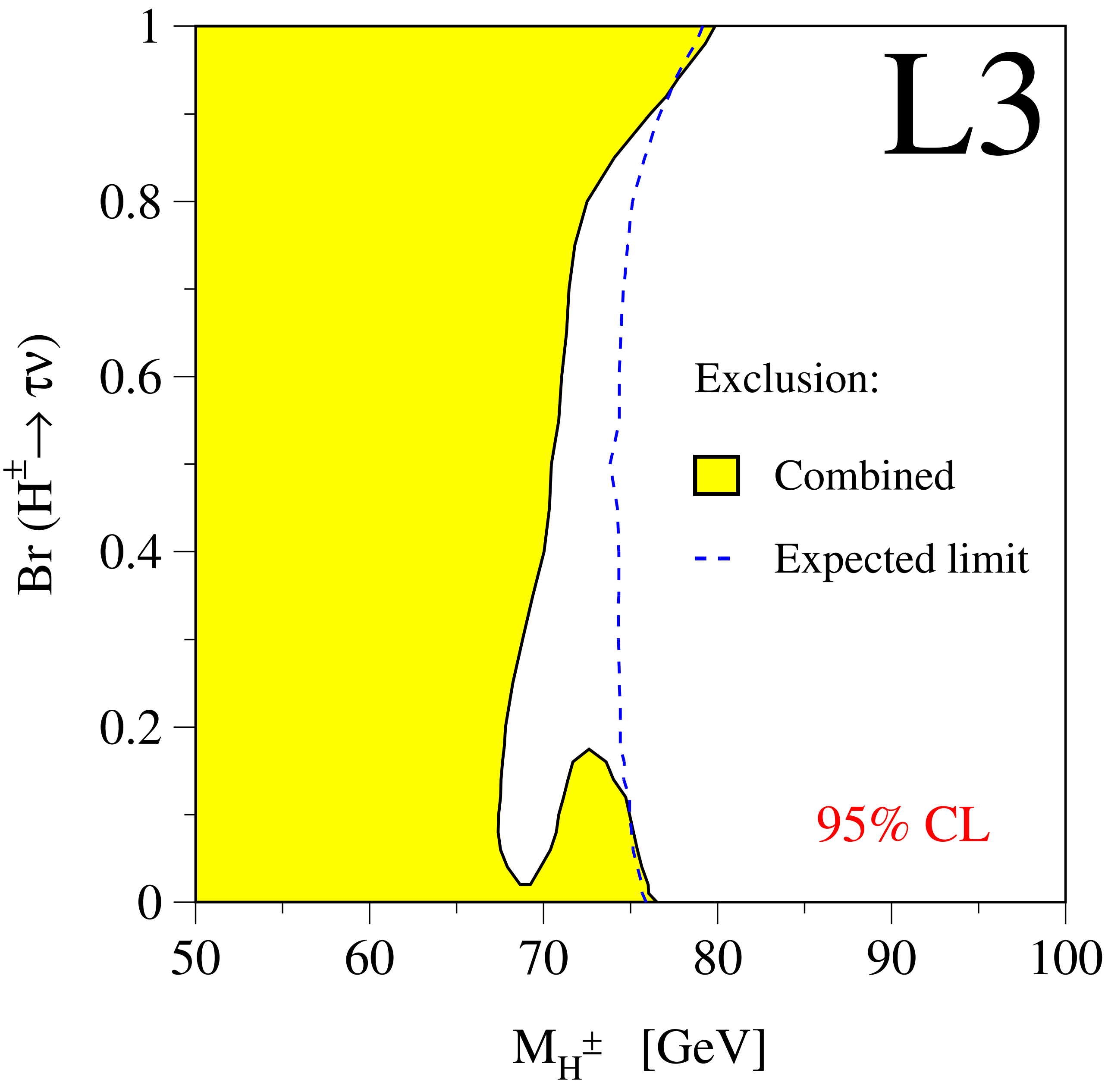

Figure 4: Excluded regions for the charged Higgs boson at 95% CL in the plane of the branching fraction $\mathrm{Br}(\mathrm{H}^{\pm} \to \tau\nu)$ versus mass. The dashed line indicates the median expected exclusion in the absence of a signal.

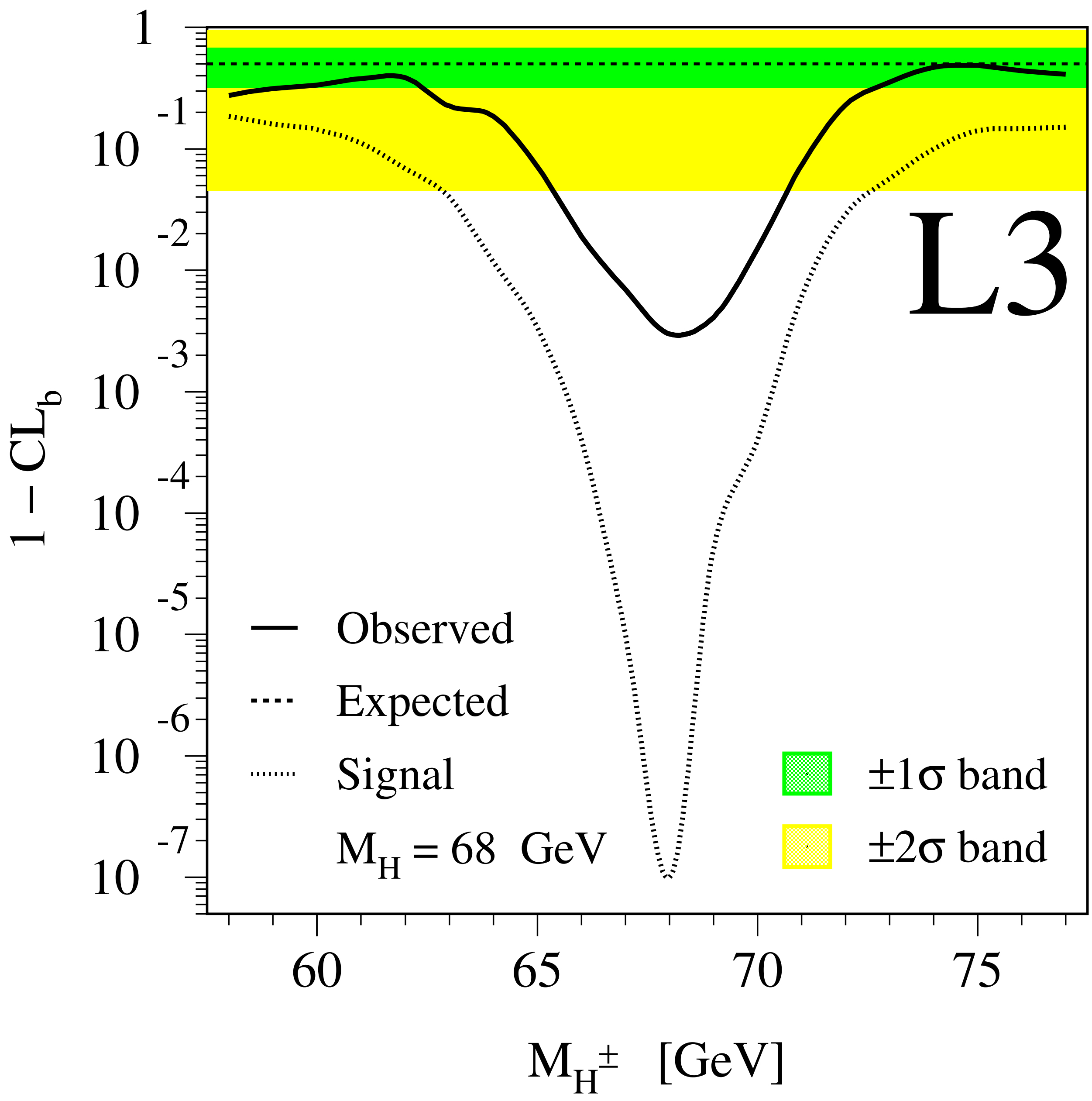

Figure 5: The observed (solid line) and the median expected (dashed line) background confidence level as function of the Higgs mass at $\mathrm{Br}(\mathrm{H}^{\pm} \rightarrow \tau\nu) = 0.1$. The dotted line is the background confidence level expected for a 68 GeV Higgs signal at this value of the branching fraction. The shaded areas represent the symmetric $1\,\sigma$ and $2\,\sigma$ probability bands expected in the absence of a signal.

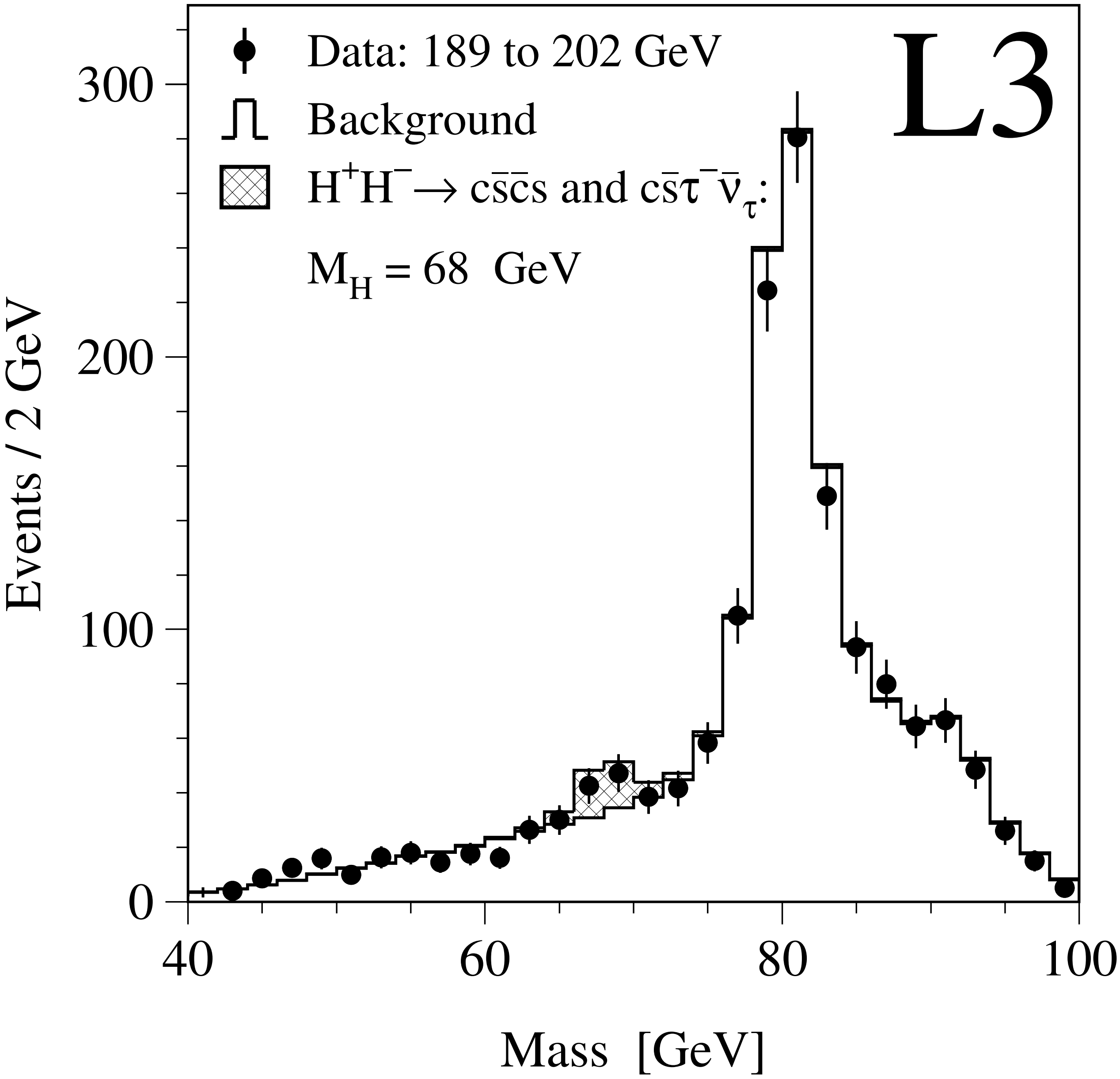

Figure 6: Reconstructed mass spectrum for data and background events in the $\mathrm{H^+H^-} \rightarrow \mathrm{c\bar{s}\bar{c}s}$ and $\mathrm{H^+H^-} \rightarrow \mathrm{c\bar{s}}\tau^-\bar{\nu}_\tau$ channels combined. Events from these two channels are weighted with the respective cross sections corresponding to a value of $\mathrm{Br(H^\pm \rightarrow \tau\nu)} = 0.1$. The expected distribution for a 68 GeV Higgs at $\mathrm{Br(H^\pm \rightarrow \tau\nu)} = 0.1$ is overlaid.